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THE VARIABILITY OF
LUNAR SURFACE MODELS
AND SURFACE CONSIDERATIONS
FOR THE LUNAR LOGISTICS VEHICLE STUDY

by

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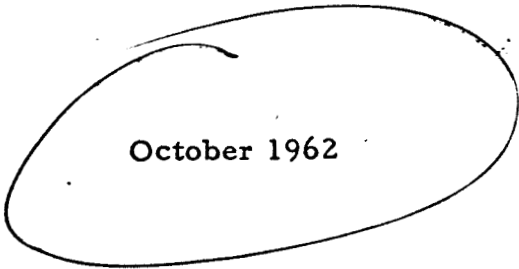
PROGRESS REPORT TO SYSTEMS STUDY OFFICE
M-AERO, MARSHALL SPACE FLIGHT CENTER

LUNAR LANDING DYNAMICS

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PHYSICS AND ASTROPHYSICS BRANCH
RESEARCH PROJECTS DIVISION
MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

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1. Work Statement
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WORK ACCOMPLISHED DURING THE FIRST SIX WEEK PERIOD

1. In the first two weeks of the six week work period, a preliminary model of the lunar surface was prepared and issued. The model was a first step modification of the Office of Manned Space Flight Working Paper LLS-SSG-1001, the basic model for the Lunar Logistics Vehicle Study.

2. During the following three weeks, the work was directed toward a study of regional features in the Ocean of Storms including the area from 8° South to 12° North of the lunar equator. Information on file, and past studies were used as much as possible in this effort. These studies are not complete, but some discussion of the area based on the work done so far is included in this report. Further studies were made during this period on rock materials analogous to those listed in the OMSE model.

3. The sixth week was spent drafting and revising figures and drawings for the report. Assistance in the drafting was provided by M-AERO-SSO. All material included in the Progress Report should be regarded as summaries of working papers.

John Bensko

Lunar Models

A model for the lunar environment was described by the Jet Propulsion Laboratory in 1960. The document contained the environmental criteria which served as the basis for the design of the first unmanned lunar scientific vehicles. The basic objective for the lunar model at that time was that it specify a single low risk lunar environment for spacecraft. This model was prefaced with the caution that the landing site be located in a "Maria-like" region. The properties of the landing site described in the model are listed in Table I and may be compared with later models prepared by OMSF and MSFC for the Lunar Logistics Vehicles study. The differences in these models do not reflect a different concept of the moon's surface so much, but rather indicate the degree to which the designer is allowed to exercise variations in environmental parameters affecting the vehicle's design.

It was necessary, at the time the J. P. L. model was written, to overcome the influence of many conflicting opinions regarding the moon's surface. The prevailing uncertainties concerning the lunar surface had a debilitating effect on the straightforward design of a lunar landing vehicle structure. Further, widely diverging views of the nature of the moon's surface led to a reluctance on the part of many engineers to design for an unknown

condition without further and unattainable information. In other cases, designers were prone to conceive vehicles of unnecessary complexity to cover all possible landing situations. The JPL model, despite criticisms at the time it was written, served a valuable purpose; namely, to direct the engineer's efforts toward vehicle and hardware problems rather than those of a cosmological nature. The model was restricted to a description of the simple geometry of a landing site with simple physical properties. In the same manner, other aspects of the lunar environment which were not vitally important to hardware considerations in the unmanned vehicle were, in a straightforward manner, listed as unimportant in the model.

A later model, now used as a basis for design studies of the NASA lunar logistics landing vehicles, is the hypothetical lunar surface described in OMSF-LLS-SSG-1001 issued in August, 1962. The model differs from the JPL model in its treatment of the lunar surface in that some concept of the average values of magnitudes of lunar features are given to acquaint the designer with the gross character of the moon. Both mare and crater surfaces are treated as landing sites. Many similarities are evident, however, between the present model and the JPL model (Table I). For instance, a degree of maneuverability (500 feet)

TABLE I

MODEL	JPL ¹	OMSF ²	MSFC ³
Parameter description	(mare-type site) average value	--	Landing site in Region 10° N to 10° S of Lunar Equator - Ocean of Storms and adjacent uplands - average values
Crater diameter	--	Avg. 80 mi.	--
Crater wall height from floor to rim	--	Avg 14,000 ft	--
Crater wall height above surrounding area	--	Avg 7,000 ft	--
Slope of crater walls	Slopes greater than 15° will not be encountered	less than 30°	Defined below
Slope of crater floor	--	Avg 5°	--
Slopes on outer rim of large and small craters	--	--	3° to 8°

1. Buwalda, P - Memo to Division 32 Engineers and scientists, P.Buwalda 10/14/60.
2. A hypothetical model of the lunar surface for use in lunar logistics Systems Studies working paper LLS-SSG-1001, NASA Office of Manned Space Flight, August 1962.
3. Bensko, J and Cortez, J., Preliminary Lunar Surface Model for Lunar Logistics System Study - MSFC Sept. 1962.

MODEL	JPL	OMSF	MSFC
Slope on inner rim of large crater (greater than 50 Km)	--	--	15° ^{max}
Average slope on the floor of large craters (greater than 50 Km)	--	--	3°
Slopes on inner rim of small craters (less than 10 Km)	--	--	30°
Highest mountains and ranges (elevation)	--	30,000 ft	--
Highest mountain ranges (slopes)	Slopes greater than 15° will not be encountered	less than 30°	--
General Maria slope	--	less than 3°	3°
Dome diameters	--	--	Several Km.
Dome slopes	--	--	2°
Ridge height	--	--	up to ^{0.2} 1 Km ✓
Ridge slopes	--	--	5°

MODEL	JPL	OMSF	MSFC
Ridge width	--	--	few kilometers
Rill depth	--	--	$\frac{1}{2}$ Km
Rill width	--	--	5 Km
Walled plains inner slope	--	--	15°
Obstructions	Protuberances larger than 10 centimeters will not be encountered	Protuberances larger than 10 centimeters will be avoided by maneuver	--

is assumed in the OMSF model which enables the vehicle to avoid local areas with obstructions larger than 10 cm (approximately 4"). This feature, coupled with an allowed regional area selection capability, provide essentially the same low risk condition as the JPL report. For example, in the JPL model, obstructions greater than 10 cm would not be encountered by the vehicle.

The preliminary MSFC model is restricted to a description of lunar landing sites in the Ocean of Storms (Oceanus Procellarum) in the region 10° North to 10° South of the Lunar Equator. Since the model is intended as a modification of LLS-SSG-1001 and not a substitute, only those aspects of the surface that appeared to require more definition were included. Where descriptions in the LLS-SSG-1001 model did not necessarily apply to the region of the moon in the Kepler-Copernicus-Lansberg area in the Ocean of Storms, they were omitted in the MSFC model.

The MSFC Model - Basic Considerations

The lunar model is perhaps a poor but necessary compromise between the known and surmised aspects of the moon's environment. A knowledge of lunar details on the order of the size of the vehicle are lacking and apparently will remain so until high resolution photographs become available from successful lunar vehicle missions. Large features on the moon's surface approximately a kilometer in size, and regional characteristics may be

seen and studied from the better earthside photographs. Careful study of photographs and visual observations constitute a beginning in our knowledge of the moon's surface character. Visual, photographic and instrumented observations, coupled with laboratory experiments, help to provide further knowledge of the environment in which a lunar vehicle is expected to perform. This, perhaps, is sufficient for conceptual design but leaves a void that must be filled for serious studies of actual flight hardware. To fill this gap to any degree recourse must be made to artificial lunar surfaces based primarily on earthside laboratory and geological field experience. The value of the design in such a case may depend on its adaptability to a range of surface conditions.

There does not appear to be a single model whose characteristics are applicable to the entire surface of the moon. Indeed, even in an area restricted to the equatorial region in the Ocean of Storms there appears to be several variations in the type of lunar surface represented.

Lunar Landing Site Topography

Crater Diameters

Surface characteristics of the Kepler, Lansberg and Copernicus areas have been studied with regard to their regional characteristics.

For craters above 0.7 Km and below 6 Km in diameter the relative frequency of their occurrence is as follows:

TABLE II

Diameter in Km		AREA		
Greater than	Less than	Kepler	Lansberg	Copernicus Riphaeus Mts.
0.7	2.0	39.0%	39.7%	46.5%
2.0	3.0	36.7%	32.8%	37.0%
3.0	4.0	15.7%	15.4%	10.1%
4.0	5.0	4.9%	6.9%	5.0%
5.0	6.0	0.7%	2.8%	0.9%

Histograms showing the crater distribution in each of the areas outlined in Table II are included in the Appendix (Figs 1,3, and 5). Accompanying each histogram is a skematic representation of the size and areal distribution of craters larger than 0.7 Km. (Figs 2,4, and 6).

Maneuver capability

The maneuverability requirement for the landing vehicle can be calculated in two fashions. One can either determine size of unwanted obstacles or areas and allow for miss capability or one can determine a desired landing location and calculate the areal extent of the largest obstacle to be avoided.

In regards to craters where one wishes to avoid the inner rim, Table III shows the percentage of craters in each region which may be avoided with a given maneuverability capability. The large craters (diameter greater than 6 Km) are not considered assuming they may be avoided by a rough area selection.

TABLE III

<i>Vehicle</i> Maneuver Capability in Km	% of craters* that can be avoided		
	Kepler Area	Lansberg Area	Copernicus Area
0.5	39.0	39.7	46.5
1.5	75.7	72.5	83.5
2.0	91.4	87.9	93.6
2.5	96.4	94.0	98.6
3.0	97.1	97.0	99.5

* Craters greater than 0.7 Km and less than 6 Km.

The assumption is not implied that any region outside of the smallest craters resolved by earth based telescopic observations are completely flat. Current opinions expressed in the literature and the size-frequency distribution of the visible craters leads toward the conclusion that still smaller craters are perhaps in the majority. On the other hand the hazard from steep-wall small craters may be diminished as a consequence of the impact process itself. Succeeding impacts of cosmic debris leads to the modification or destruction of crater forms on which they impact. Such a process would have a degrading effect on the larger craters. On smaller craters this action would lead to a complete modification of the crater shape. Leveling action caused by the shock generated from meteorite impact with the moon's surface coupled with fine debris scattered as a result of mechanical breakage of lunar material, should also lessen the hazard from holes resulting from the presumed greater influx of smaller particles. Perhaps even a greater source of leveling occurs from the debris ejected by the rayed craters (Appendix, Figs 7,8, and 9). While estimates on the thickness of such cover material varies any thickness should soften the effects introduced by impact.

Obstructions (Blocks of Rock)

Although the unmanned hard landing vehicle model appropriately places an upper limit on the obstructions that a vehicle should be designed to encounter, this should not be taken to mean that larger obstructions do not actually exist in quantity in many areas on the moon. The maneuver capability described for crater wall evasion in the previous paragraphs may be used to advantage in the actual lunar landing situation to avoid isolated obstructions. Our experience with the size frequency distribution of debris associated with cratering processes on the earth is rather limited. Some studies have been made. It is not quite certain presently, however, as to the degree to which this is applicable to the lunar features of equivalent size and visual appearance. The maximum block size associated with earth craters ranging in size from meteor crater (Arizona) to small explosion craters has been investigated by Moore, Gault and Lugin (Appendix, Fig 10). Some work has been done toward assessing the area covered by broken rim and blocky material and outlining these areas from the smoother appearing maria on charts. These are not included in the interim report.

Regional Elevations and Slopes

An idea of regional topography in the areas shown by the index maps, (Appendix, Figs 11, 13 and 15) are provided by regional cross-section charts (Appendix, Figs 12, 14, 16 and 17). Regional

slopes vary to some degree from crater to crater and slopes vary locally on a crater rim. Copernicus, the largest crater included in the cross-section charts has a lower regional slope on its rim than do the smaller craters, but steep local slopes from large blocks of debris are possible. Cross-sections showing inner slopes of two earthside craters are shown in the Appendix (Figs 18 and 19). Relative heights of crater rims above floors and above the surrounding area differ somewhat in the three areas shown. The largest of these differences are as follows:

Area	Kepler	Lansberg	Copernicus	Riphaeus Mts.
Elevation of rim above crater floor in meters	1000	3000	3000	--
Elevation of crater rim above surrounding area	600	600	900	--
Elevation of mountains above surrounding area	--	--	--	600

Soil Mechanics

Considerable effort has been expended in the study of soil mechanics particularly in regards to laboratory studies in a controlled environment.

Since rock froth is a prominent part of the OMSF surface model, some study was made into the properties of artificial and natural rock of this type. Recent studies and tests of rock froth indicate that the bearing strength of this type material may range from 6 psi to approximately 100 psi in man-made rock froth samples. Since rock froth may vary considerably in physical character, degree of vesicularity, etc, from sample to sample, material still identifiable as a froth could conceivably have a bearing strength up to approximately 200 psi. In the natural state one would expect considerable lateral and vertical variation in the strength of this type material. The lower range of values obtained for rock froth samples are preferable for the lunar model.

Compressive and shear strength of sand and silt tested in atmospheric environment may not be directly applicable to granular rock particles on the moon's surface.

Lunar gravity would allow less dense packing of clastic material. For loose material on the moon lunar gravity and high vacuum together with the character of the shape of the particles

will tend to influence the rock material characteristics. The value given in the preliminary MSFC model for sand-silt combination, however, will not be altered until tests are made in vacuum varying both the shape and size of the particles and with low "g" packing.

Solid rock should be expected to have considerable strength on the moon as it does on the earth.

Preliminary MSFC Model (September 1962)

The following model represents a modification of the surface model described in the OMSF working paper LSS-SSG-1001. It should be understood that lunar details on the order of the size of the landing vehicles cannot be resolved with earth bound telescopes. More microscopic details of the surface may be surmised from photometric and polarimetric studies in conjunction with laboratory experiments. Radar studies still require additional refinement.

Since there is not a single model applicable to the entire surface of the moon, four surface models representing varying morphology will be provided as the study progresses. These models; of the landing areas in the region 10° N and 10° S of the lunar equator, including maria and upland areas, will present the degrees of difficulty in the surface condition as outlined in the Koelle memo.

(A) LANDING SITE TOPOGRAPHY

1. Maria

- (a) Average regional slope 3°
- (b) Average slopes on outer rim of large craters (50-100Km) 3 to 8°
- (c) Average slopes on inner rim of large craters 15°
- (d) Average slopes on the floor of large craters 3°
- (e) Average slopes on outer rim of small craters 3 to 8°
- (f) Average slopes on inner rim of small craters 30°
- (g) Average slopes on inner rim of craterlets
(less than 10 Km Dia.) 30°

(h) Crevasses: cracks on the order of vehicle size may
be present near or on the crater rim and should also
be expected on the periphery of the maria.

(i) Domes: mounds with low slope ($\sim 2^\circ$ over regional)
several kilometers in diameter.

(j) Ridges: low ridges, with slopes $\sim 5^\circ$ with elevations of
a few hundred meters and a width of a few kilometers.
(according to Van Diggelen's photometric measurement)

(k) Rills - linear depressions with flattened or convex floors:
approximate depth 100 to 500 meters, approximate width 2 to
5 Km.

2. Uplands

- (a) Crater geometry essentially same as those on Maria.
- (b) Walled plains, inner slopes approximately 15° . Slight or
no external rim.

(B) SOIL MECHANICS OF UPLANDS AND MARIA

1. Maria

- (a) Surface consists of recent debris in the form of ray patterns 5 to 10 kilometers across composed of loosely packed spherical grains approximately 2 mm in diameter (Bulk density of 1 to 1.5 g/cc). The surface beneath and adjacent to the ray debris consists of bonded and/or loose fragmented material, largely of sand grain to small boulder size; boulders are in a matrix of bonded finer particles. This, in turn, may overly lenses of brecciated material and porous fused rock.

Adjacent to crater rim (approximately 1 radius) material consists of large blocks of fractured rock, some with high angles of repose, grading into a mixture of rubble and pulverized rock. The interior of ancient craters should consist of rock powder, which, except for the uppermost portion, should be bonded.

2. Uplands

- (a) Surface material consists of bare rock with irregular concentration of finely divided silt or sand size (approximately 0.3 to 2.0 mm) fragments. Accumulations assumed: a few centimeters deep on low slopes with greater concentrations in local basins. This overlays a thick layer of rubble mixed with fragments of porous materials.

3. Frictional Properties: When the landing pad or pads slide on the lunar surface material, two actions occur: One, junctions between the pad and the contacted surface are formed and sheared; two, the harder surface gouges out the softer material. Tests have been made on the earth for slide of various material over several surface types. Under the influence of high vacuum environment, a measure of the coefficient of friction should be higher than that obtained under normal atmospheric conditions. As a basis for beginning some initial considerations, however, some results from earth-based experiments are given as follows:

Base Material	Coefficient of Friction		
	1620 Steel Slider	Beryllium Copper Slider	Tungsten Carbide Slider
Dry lubricated (sand & silt)	0.45	0.45	-
Dry concrete (hard rock)	0.35	0.35	0.20
Loose Aggregate asphalt (loosely bonded pebbles)	0.25	0.40	0.20

4. Load bearing strength:

- (a) Indurated rock material 300 psi
- (b) Gravel & coarse sand 50 psi
- (c) Rock froth 6-200 psi

APPENDIX

- Fig 1. Histogram showing the size frequency distribution of invisible craters in the Kepler-Encke-Kunowsky Area.
- Fig 2. Schematic representation of the distribution of invisible craters in the Kepler-Encke-Kunowsky areas.
- Fig 3. Histogram showing the size frequency distribution of visible craters in the West Lansberg Area.
- Fig 4. Schematic representation of the distribution of visible craters in the West Lansberg Area.
- Fig 5. Histogram showing the size frequency distribution of visible craters in the Copernicus area.
- Fig 6. Schematic representation of the distribution of visible craters in the Copernicus area.
- Fig 7. Ray material in the Kepler-Encke-Kunowsky Area.
(USAF Atlas)
- Fig 8. Ray material in the West Lansberg Area
- Fig 9. Ray material in the Copernicus area.
- Fig 10. Maximum block size of crater debris.
- Fig 11. Index map showing location of lunar cross sections in the Kepler-Encke-Kunowsky Area.
- Fig 12. Idealized cross sections of Kepler, Encke and Kunowsky
- Fig 13. Index map showing location of lunar cross sections in the Lansberg Area.
- Fig 14. Idealized cross sections of Lansberg and the Rhipaeus Mountain region.
- Fig 15. Index map showing location of lunar cross sections in the Copernicus area.
- Fig 16. Idealized cross section of Copernicus.
- Fig 17. Idealized cross section of Reinhold-Reinhold B.

APPENDIX

APPENDIX (CONT'D)

Fig 18. Cross section of an explosion crater.

Fig 19. Cross section of a small meteor crater.

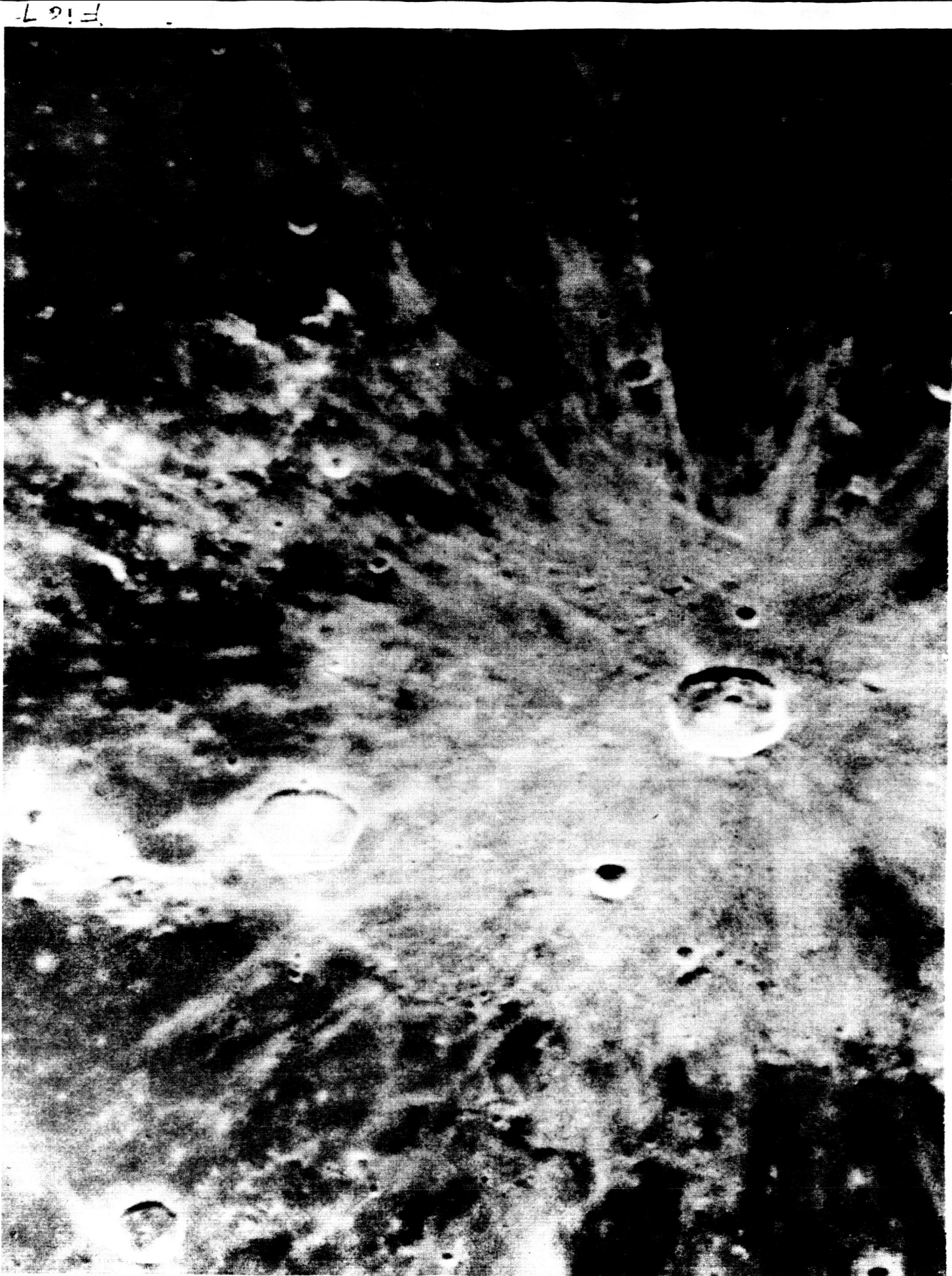
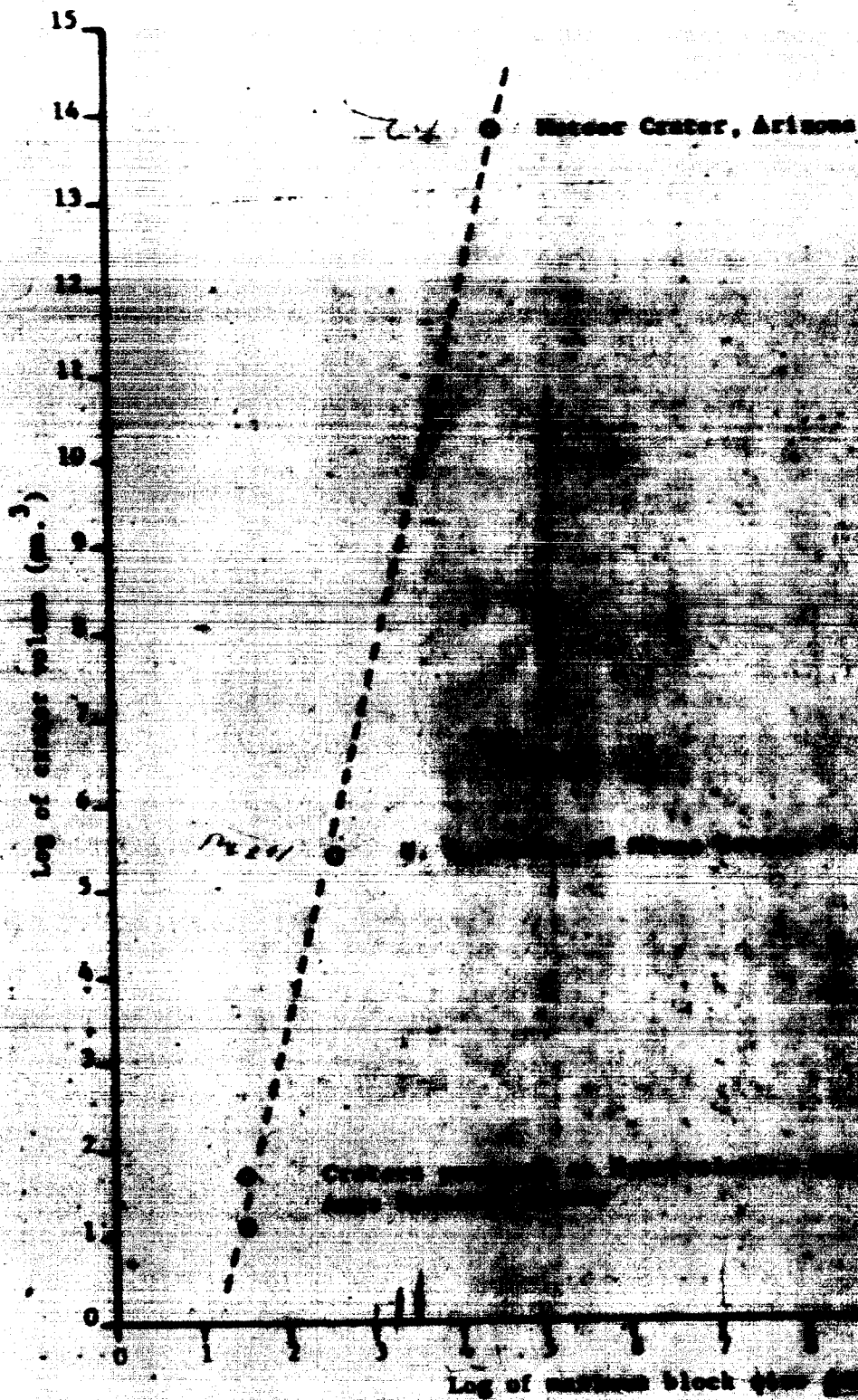




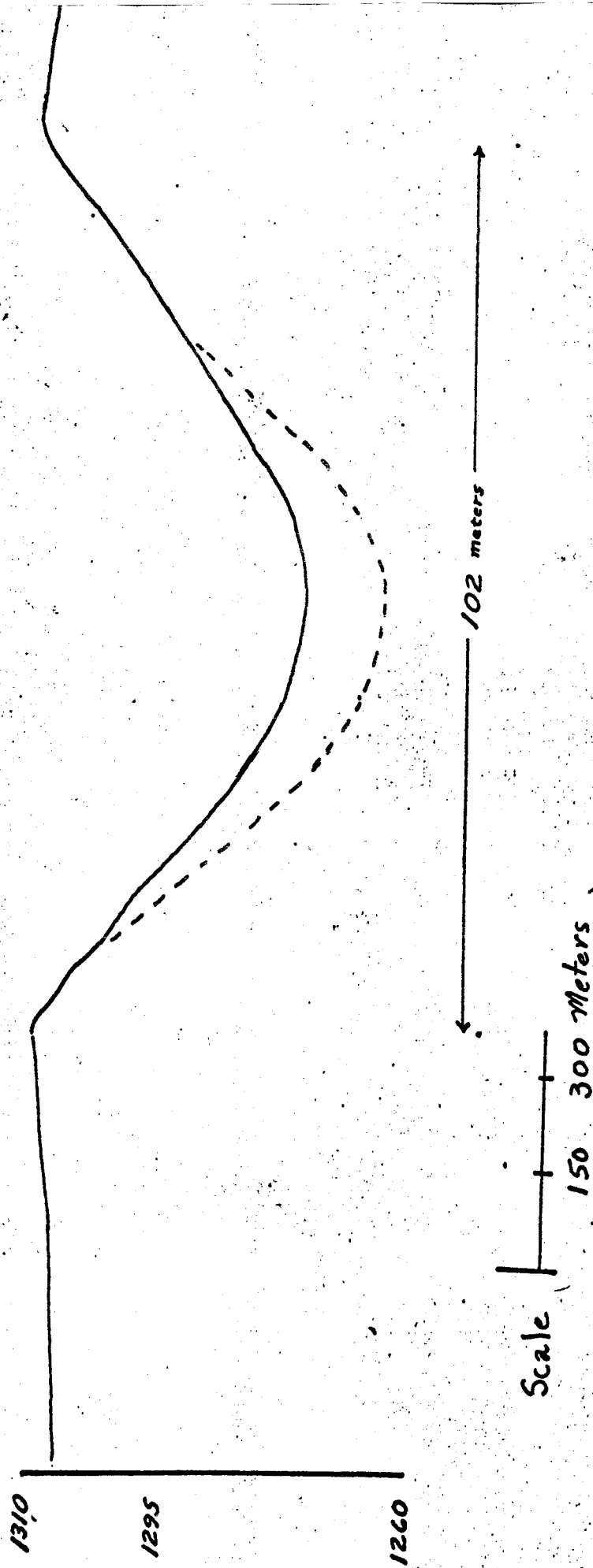
FIG. 9



FIG 9



Relationship between crater volume and maximum block size of craters
 After Moore, Gault and Luga, Astrogeologic Studies, 1960, General



CROSS SECTION OF AN EXPLOSION CRATER

BASED ON TEAPOT ESS CRATER (NEVADA)

CROSS-SECTION OF A SMALL METEOR CRATER (BASED ON METEOR CRATER, ARIZONA)

